/833

O–82003

DRILL CUTTINGS

ON THE SEA BED

Field experiment on
recolonization and
chemical changes

PHASE 1

Thick (10 mm) layers of cuttings
1982 – 1983

One year extension 1983 – 1984

Norwegian Institute for Water Research NIVA

NIVA - REPORT

Norwegian Institute for Water Research ⬥ NIVA

Main Office
P.O.Box 333 Blindern
N-0314 Oslo 3
Norway
Phone (47 2)23 52 80

Regional Office, Sørlandet
Grooseveien 36
N-4890 Grimstad,
Norway
Phone (47 41)43 033

Regional Office, Østlandet
Rute 866
N-2312 Ottestad
Norway
Phone (47 65)76 752

Regional Office, Vestlandet
Breiviken 2
N-5035 Bergen - Sandviken
Norway
Phone (47 5)25 53 20

Report Title:	Date:
DRILL CUTTINGS ON THE SEA BED Field experiment on recolonization and chemical changes. Phase 1. Thick (10 mm) layers of cuttings 1982-1983. One year extension 1983-1984.	9. april 1986

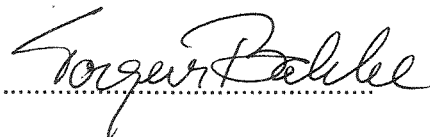| Author(s):	Topic group:
Bakke, Torgeir Green, Norman W. Næs, Kristoffer Project leader Pedersen, Are *Sporstøl, Sigve (SI)* *Oreld, Frøydis (SI)*	Marine ecology
	Geographical area: Hordaland
	Number of pages (incl. app.) 34

Contractor:	Contractors ref. (or NTNF - No)
Mobil Exploration Norway Inc. on behalf of the Statfjord Unit Owners	S.R. Olsen

Abstract:

Cuttings from drilling with water based mud (WBM-cuttings), low aromatic oil based (LAC-cuttings, a first generation low toxic mud), diesel oil based mud (DOC-cuttings) and diesel oil based mud compressed into solid briquettes (BRI-cuttings) were placed in 10 mm thick layers on top of 12 cm natural sea bed sediment in 1x1x0,24 m trays. The trays were left on the sea bed, 11 m, for 2 years. During the second year no further loss in total hydrocarbons or aromatic hydrocarbons (NPD) was detected. Indication of biological degradation of the oil was found after 15 months, and even more so after 24 months.
Benthic fauna recolonization clearly distinguished oiled from nonoiled substrates during the first year and this was even more pronounced the second year. Fauna development in reference sand and WBM cuttings was considered normal, whereas the poor fauna of the LAC, BRI and DOC cuttings collapsed completely the second year. No sign of fauna recovery from the discharge was detected after 2 years, irrespective of the type of base oil on the cuttings.
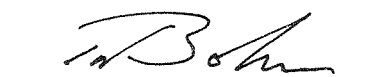
4 keywords , Norwegian	4 keywords, English
1. Borekaks	1. Drill cuttings
2. Felteksperiment	2. Field experiment 1983-84
3. Benthisk rekolonisering	3. Benthic recolonization
4. Kjemiske forandringer	4. Chemical changes

Project leader

For the Administration

O-82003

DRILL CUTTINGS ON THE SEA BED
Field experiment on recolonization and chemical changes
Phase 1. Thick (10mm) layers of cuttings

1982 - 1984

One year extension
(1983-1984)

Project leader: Kristoffer Næs
Co-workers: Torgeir Bakke
               Norman W. Green
               Sigve Sporstøl (SI)
               Frøydis Oreld (SI)

NORWEGIAN INSTITUTE FOR WATER RESEARCH

P R E F A C E

This document reports the results from 1 year extension of the Norwegian Institute for Water Research project formulated in research proposal of May 25 1982:

"Project to investigate the recolonization of benthic organisms on sedimentary bottoms covered by discharged drill cuttings and the possible leakage of contaminants to the water".

This proposal suggested a one year experiment: June 1982 to May 1983. It was later decided to extend the experiment for another year, but with lower effort in sampling. The results from this one year extension (May 1983-May 1984) is reported here. The total experimental period for the Phase 1 project has therefore been 2 years.

ACKNOWLEDGEMENTS

T A B L E   O F   C O N T E N T S

1 SUMMARY AND MAIN CONCLUSIONS

A field experiment was conducted June 1982 to May 1984 to investigate the suitability of cuttings as substrate for a benthic community. The experiment comprised four types of cuttings deposited in open trays on the sea bed (11m depth) from drilling with water based mud (WBM cuttings), low aromatic oil based mud (LAC cuttings), diesel oil based mud (DOC cuttings), and cuttings with diesel oil based mud compressed to briquettes (BRI cuttings). The cuttings were laid out i 10mm thicknesses on top of defaunated natural sea bed sediment.

The results from the chemical analyses from the first 12 months of the experiment showed a significant decrease in content of selected aromatic hydrocarbons (NPD) with time for all three oil based cuttings. The most prominent reduction was found during the first four months on the sea bed. Except for the BRI no significant reduction was found in the total amounts of oil hydrocarbons (THC). The difference betweeen NPD and THC is explained by the NPD's representing a minor, relatively water soluble fraction of the total hydrocarbon content.

The results from the second year of the experiment showed no significant change in hydrocarbon concentrations neither for NPDs nor THC compared with the first year.

Biological degradation, as indicated from $n-C_{17}$/pristane and $n-C_{18}$/phytane was not observed during the first 12 months of exposure. However, after 15 months, and even more so after 24 months, there was a decrease in the normal to branched alkane ratio indicating that biodegradation had occurred.

The results on animal colonization showed that the clear distinction in fauna development between oiled and non-oil substrates, wich was recorded during the first year, became even more pronounced during the second year. The reference and water based cuttings kept the same animal densities during the second year as in the first year, whereas the number of species and hence diversity decreased somewhat, presumably as a result of natural stabilization through competition and predation. The second year density decrease was reflected in most animal groups present, most clearly in the bivalves, but did not result in higher dominance by any particular species.

In the oiled substrates the poor communities which had developed during the first year, collapsed in the second year, resulting in a fauna with diversity index value close to zero and 100% dominance of the opportunistic polychaete Capitella capitata, being the only macrofauna species present. The fauna of the oiled substrates was confined to a layer of detritus on top of the cuttings. The reason for the community collapse could have been a gradual increase in toxic components in the detritus from biodegraded hydrocarbons, or that the detritus layer itself could not support a permanent macrofauna. The latter could be due to lack of stability of the detritus due to

settling and resuspension of matter.

The results from the second year of the experiment demonstrated that in spite of the slight temporary improvement of the low aromatic cuttings over diesel cuttings during the first year, no real sign of biological recovery from the discharge could be found within two years, irrespective of the kind of base oil used in producing the discharged cuttings.

2 Introduction

Offshore drilling activity causes discharge of well cuttings and drill mud to the marine environment around the drilling platform. According to the type of well drilled and the stability of penetrated formations, different make-up fluids are used to formulate the proper drill mud. Offshore drilling often employs water-based drilling fluids, which often show little or no toxicity to marine organisms. However, the activity in the North Sea, and in particular the Statfjord area, implies drilling in formations that are unstable when contacted with water. In addition, a large number of highly deviated wells are to be drilled. In such areas, oil based muds have several advantages over water based formulations. The base oil can be diesel, or to an increasing extent, a low-aromatic mineral oil.

A cuttings treatment procedure practiced at Statfjord A during the period prior to this investigation was as follows: After retrieval from the well, the diesel cuttings and mud were separated and the drill cuttings were washed with diesel oil. After removal of excess diesel oil the cutting were washed down a sluiceway with sea-water and discharged about 40 meters above the sea floor.

Field surveys at the Statfjord field in 1979 and 1980 revealed that a bottom area of about 2 and $10km^2$, respectively, contained elevated levels of hydrocarbons orginating from the discharged cuttings (Grahl-Nielsen, 1981). Simultaneous biological investigations in 1980 showed small, yet significant differences in the composition of benthic macrofauna inside and outside this area (Bakke, 1981).

As the discharge is tied to drilling it must be considered a temporary problem, terminating when the drilling is finished. However, it is important to investigate how the areas most influenced by sedimented cuttings will recover when drilling stops: the duration of a potential toxicity of the waste material, the leakage of possible harmful substances to the overlying water, the colonization of benthic organisms in covered areas and the development of the benthic communities in these areas compared to unaffected areas.

The objectives of the project reported here were therefore to investigate:

1) The suitability of various types of discharged cuttings as substrates for the establishment of a benthic community. In particular the characteristics and intensity of colonization by settling larvae of macrofauna were to be studied.

2) The chemical/biological degradation and rate of release with time of hydrocarbons and metals to the overlying water, from the same types of discharge as in the colonization studies.

This report is a supplementary volume to the main document of the Phase 1 experiment (Bakke & al. 1985a) and reference is made to the latter for a complete description of materials and methods.

3 Materials and Methods

The basic experimental principle adopted was to deposit the relevant discharge material on the sea bottom for invasion by benthic organisms and for the material to be influenced by natural physical and chemical environmental factors.

3.1 Experimental site

The test material was positioned on near level sand bottom at 11m depth in Raunefjorden south of Bergen, Western Norway (Lat. 59° 14.3'N, long. 5° 17.3'E, cf.Fig. 3.1). The site is in convenient distance from the facilities of the Department of Marine Biology, University of Bergen. The communities in shallow waters of the west coast have several similarities with those of the North Sea with respect to salinity and temperature regime, species composition and individual sizes.

3.2 Duration

The main experiment started in June 1982 and lasted one year to May 1983 (a total of 11 sampling dates). The experiment was later extended one more year with 2 additional sampling dates: 28 September 1983 and 22 May 1984.
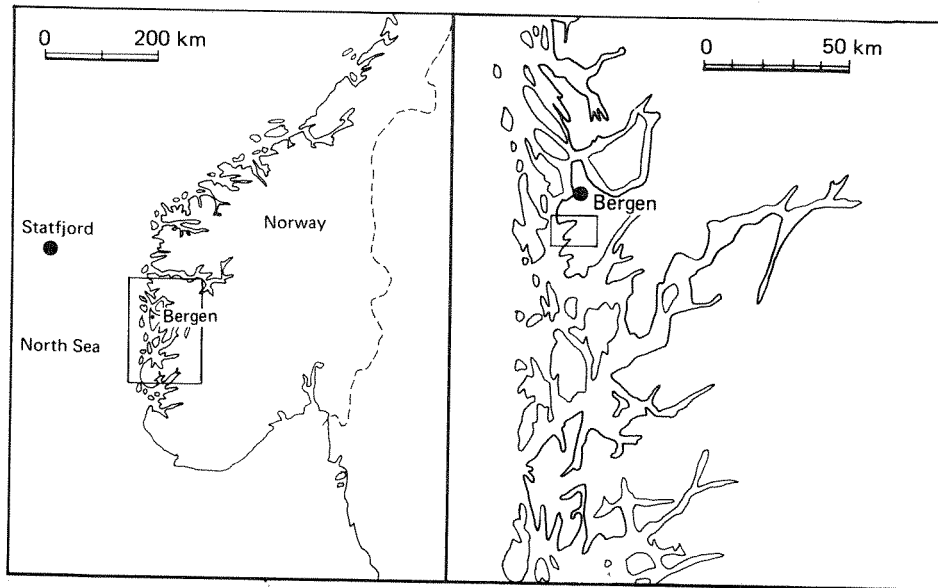
Fig. 3.1   Location of the experimental site near Bergen Norway

3.3 Experimental design

Trays (0.6x0.4x0.25m and 1x1x0.20m) were filled with a 12cm layer of sea bed sediment deprived of animals by freezing and thawing. On top of this a slurry of sea water and the relevant cuttings (2:3 by volume) was spread out in an even 10 mm layer. Four large (permanent) and four small (removable) trays were prepared for each type of cuttings. Four additional trays of each size with sea bed sediment only were prepared in the same way to be used as reference.

The trays were positioned on the sea floor at 11 meters depth in Raunefjorden, SW of Bergen, Western Norway, in June 1982 and incubated for 24 months. Sampling of the tray sediment was done with diver operated corers (inner diameter 45mm).

An Aanderaa Recording Current Meter with sediment traps and probes for temperature and salinity was positioned on the experimental site.

3.4 Reference and test material

One reference sediment and four types of cuttings (listed below) were added to trays submersed on the sea bed. Details on the cuttings may be obtained from MENI.

REF   As reference material was chosen sea bed sediment collected by grab from a near-by area at 5-15 m depth and frozen to kill the excisting fauna. The sediment was thawed and sifted through 1 cm mesh. Sea water from 40 m depth and clean commercial granite sand of appropriate grain size were added in the volume proportions 3(sediment):2(water):1(sand) and the whole lot was mixed in a cement mixer.

WBM   Cuttings produced during drilling with water based mud. Source: STATOIL well, from primary shakers/mud cleaners. Screen size shakers: 80/100 mesh, cleaner: 150/200 mesh. Mud type: Gypsum, CMC, lignosulphonate system, no bacteriocide reported used.

LAC   Cuttings produced during drilling with low aromatic oil base mud. The type of cuttings received from MENI had been produced during drilling with a 'first generation' low aromatic oil based mud. This oil contained higher levels of aromatic hydrocarbons than the types presently at use (MENI pers. inf.). The cuttings were taken from 80/90 mesh screens, possibly also from mud cleaners (200/250 mesh).

BRI   Unwashed cuttings produced during drilling with diesel oil base mud as the DOM below, but compressed into briquettes.

DOC Cuttings produced during drilling with diesel oil base mud.
     Source: STATFJORD well, from fine mesh drying screen (20/40
     mesh). Mud type: Inverted Oil Emulsion Mud (IOEM).

3.5 Parameters and sample treatment

3.5.1 Hydrocarbons

The analytical procedures are in principle based on isolation of
hydrocarbons from the sample matrix followed by enrichment and
instrumental analysis. A brief description is given below and a
detailed description is given in Appendix Report A.

For samples containing low levels of hydrocarbons (REF and WBM) a
standard saponification method was applied, and the THC (total amount
of hydrocarbons) and NPD (sum of selected aromatic compounds, i.e.,
naphtalene, phenanthrene/anthracene, dibenzothiophene, and their C_1,
C_2, and C_3 alkyl homologs) values were obtained from the same extract.
The method includes saponification of 20-50 g sediment with methanolic
KOH followed by extraction with n-pentane. The extract was cleaned for
polar components by florisil.

Samples with high amounts of hydrocarbons (LAC, BRI, and DOC) were
analysed using two different methods. The NPD values were obtained
using the same saponification procedure as for samples with low
content of hydrocarbons. High level THC analysis was carried out using
sample material equivalent to the material used for NPD analysis.
Samples were not saponified, but extracted directly by use of a whirly
mixer technique. About 2 g of sediment from a 20-50 g homogenate was
extracted with 3x5 ml n-pentane on a vibrator (Fisons whirlmixer,
Appendix Report A) for periods of 2 min. After centrifugation the
combined extracts were analysed by GC.

3.5.2 Bottom fauna

The upper 0-1 and 1-3 cm sections (in September 1983) or the 0-3 cm
section (in May 1984) of one core sample from each tray were preserved
in 4% neuralized formalin to which was added 6-7 drops of Rose Bengal
stain solution (Thiel, 1966; procedure 2) to ease the discovery of the
animals. From September 1983 only the 0-1 cm sections have been
analysed for fauna. The 1-3 cm sections are stored.

Before sorting, the samples were sifted gently through 0.5 and 0.06 mm
sieves. The fauna retained by the 0.5 mm sieve was classified as
macrofauna, and fauna retained by the 0.06 mm sieve as the meiofauna.
A discussion of the separation into macrofauna and meiofauna fractions
has been given by Bakke & al. (1985b). It is more a matter of
practical sample treatment than of biological difference, since it is
much more tedious to sort and identify meiofauna than macrofauna.

When species or higher group densities were calculated, the meiofauna and macrofauna fractions of these groups were pooled. For estimates of macrofauna community indices (diversity, dominance, etc.) the "macrofauna" sized nematodes, harpacticoid copepods and unidentified larvae (only few at 0.5mm) have been excluded.

The material retained by the 0.5mm sieve (coarse fraction) was sorted separately for each core under a dissecting microscope. All individuals were classified to their main taxonomic group and counted and all except unicellular forms, nematodes, harpacticoid copepods, and mites were classified to species. Species or higher taxonomic groups are referred to collectively as taxa. The material retained by the 0.06mm sieve (fine fraction) for all 4 samples from the same type of substrate was pooled in a meiofauna subsampler (Elmgren, 1973) and divided into 8 equal portions of which two were sorted and enumerated after the same procedure as the coarse fraction.

The basic values of "numbers of individuals per core sample" were used to calculate population and community parameters for each substrate and date as described below.

POPULATION PARAMETERS

Individual density

This was calculated for each taxon as <u>the number of individuals per 0.01m^2 sediment surface</u>. The values presented are the means of the counts from the 4 parallel core samples. Standard deviation of the means have been calculated, but for clarity they have not been drawn on the graphs.

Dominance value

The density of each species as percentage of the total individual density.

COMMUNITY PARAMETERS

Number of taxa and taxonomic composition

This shows which and how many taxa are present in a substrate on each date. Individuals which could not be identified were classified into the lowest possible group and if necessary separated by numbers. Values have been computed for macro- and meiofauna separately and for total fauna.

Species diversity (H)

Diversity describes the "richness" of a community. It is based on the number of species and the densities of these. The diversity-index <u>H</u> used on these data is the Shannon-Wiener's expression for diversity (Shannon and Weaver, 1963):

$$H = - \sum_{n=1}^{s} (p_i)\,(\ln p_i)$$

where s is the number of species (or taxa) and p_i is the proportion of the total sample belonging to the i-th species. Large values of H (above 2-3) indicate a rich community, low values indicate a simple community with few species. Diversity values have been computed for macrofauna and for total fauna.

Evenness (E)

This parameter indicates separately one of the components of diversity, how the individuals are distributed among the occurring species. We have used Pielou's index $\underline{J}$ (Pielou, 1975):

$$J = \frac{H}{H_{max}}$$

where H is diversity and H_{max} equals $\log_2$ s. The values of $\underline{J}$ varies between 0 and 1. High values of $\underline{J}$ indicate that the number of individuals are evenly distributed among the different species and low values indicates that few species contain most of the individuals.

Dominance index

This parameter indicates to what extent the one most common species dominates a community. The definition of the index for benthic fauna studies was proposed by Shaw et al. (1983): the density of the most common species as percentage of the sum of all densities. Hence, the index has a maximum value of 100 (only one species present).

Dominance profile

This is a graphic presentation of dominance in a sample proposed by Shaw et al. (1983). The species are ranked by decreasing dominance values along the abscissa and the dominance value itself is scaled against the ordinate giving a curve rising towards the ordinate axis. A curve with a sharp bend upwards close to the ordinate axis reflects a dominant community, i.e., one common and one to several rare species. The more horisontal and even the curve is, the more evenly distributed are the inidividuals among the species, and hence the less is the dominance. Usually a few species will include most of the individuals. In this study inclusion of the 10 most common species was sufficient to define the shape of the profile. Dominance profiles have been constructed for macrofauna only.

4 Results and discussion

4.1 Hydrocarbons

The results from the first year of experiment indicated a significant reduction in the content of selected aromatic compounds, the NPDs (two sample t-test, Wilcoxon two sample rank test, Kendall's correlation coefficient, 95% confidence level, Sokal & Rohlf, 1969). Such reduction was not detected in the total hydrocarbon content (THC) with exception of the BRI.

The results from the second year indicated no further change in hydrocarbon concentration neither for NPD nor THC compared to the results from the first year (Fig. 4.1). Biological degradation, as indicated from the n-C_{17}/pristane, n-C_{18}/phytane and pristane/phytane ratios, was not observed during the first 12 months of exposure. However, after 15 months, and even more so after 24 months, there was a decrease in the the normal to branched alkane ratios indicating that biodegradation had occurred (Fig. 4.2).
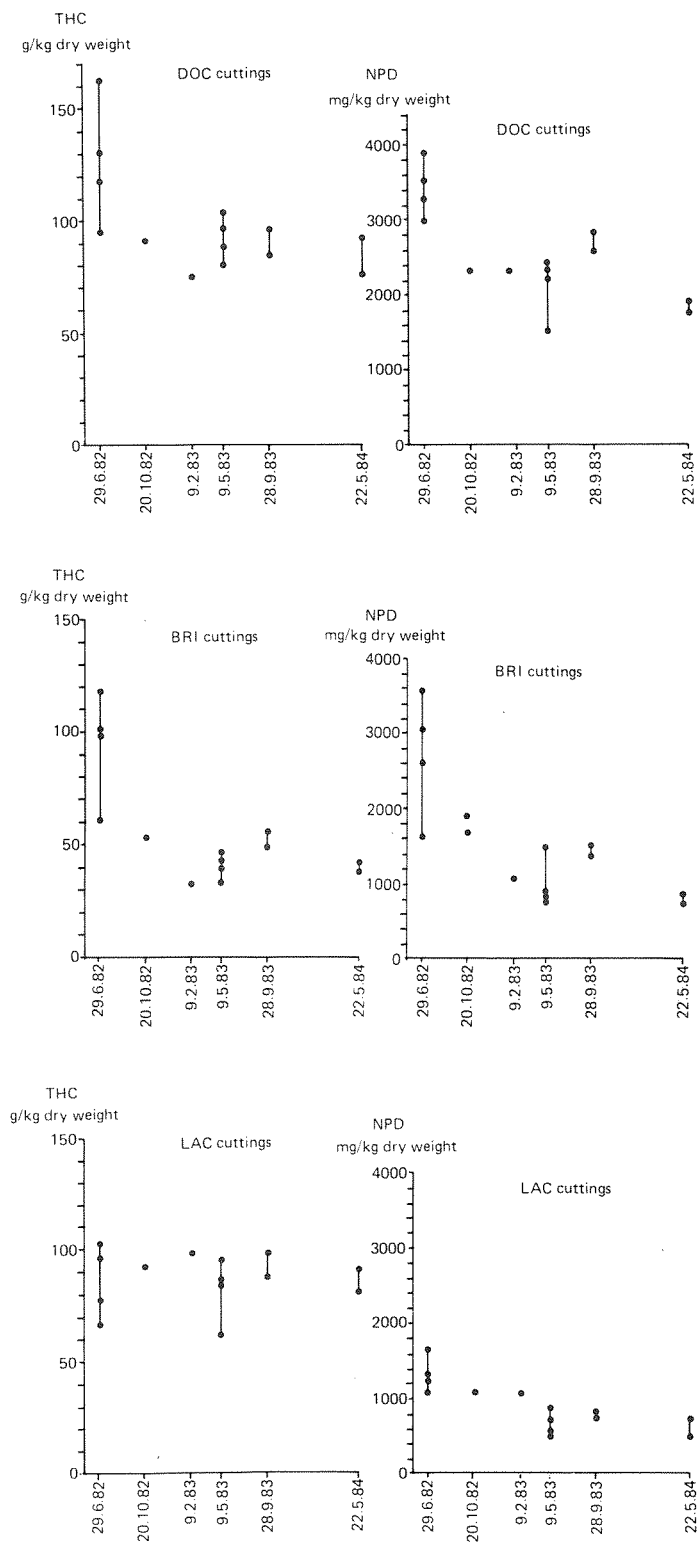
Fig. 4.1   Changes   in   total   hydrocarbons   (THC)   and   in   selected
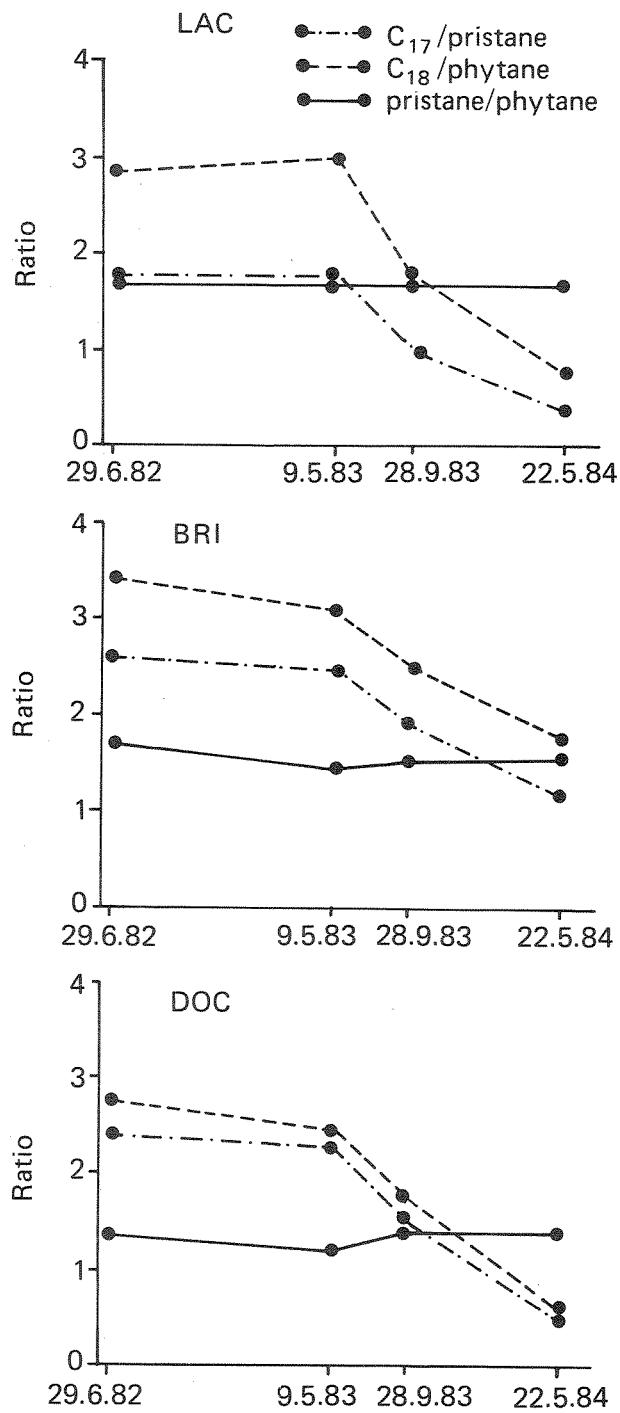aromatic hydrocarbons (NPD) with time.

NIVA:O-82003,Rekolj

Fig. 4.2   Reduction in ratios of normal to branched alkanes (C_{17} to pristane and C_{18} to phytane) indicating biodegradation. Lack of change in ratio between biogenic alkanes (pristane to phytane) is indicated.

4.2 Fauna colonization

4.2.1 Number of animal taxa

Within two weeks after exposure the numbers of macrofauna taxa in the non-oiled substrates (REF and WBM) exceeded those of the oiled substrates (LAC, BRI and DOC) (Fig. 4.3). This difference increased with time, and was statistically significant. The species richness of the non-oiled substrates peaked in August 1982, then stayed at about 25-30 taxa except for another peak to 39-40 taxa in May 1983. These peaks were also found in the oiled substrates, but the number of taxa was generally between 8 and 10 with highest value 16. After February 1983 the number of taxa found in LAC was higher than in the BRI and DOC, mainly reflecting an increase in polychaetes, but after May 1983 this slight improvement over BRI and DOC disappeared. At the end of the two years the oiled substrates had only one real macrofauna species: the polychaete _Capitella capitata_.

The number of taxa in the meiofauna size range was less than the macrofauna, since the meiofauna was classified to higher groups (Fig. 4.4). Generally, the REF and WBM substrates contained significantly higher number of meiofauna groups than the oiled substrates, but the difference was small.

The total number of animal taxa showed much the same pattern as the macrofauna since very few taxa were specific to the meiofauna (Fig. 4.5).
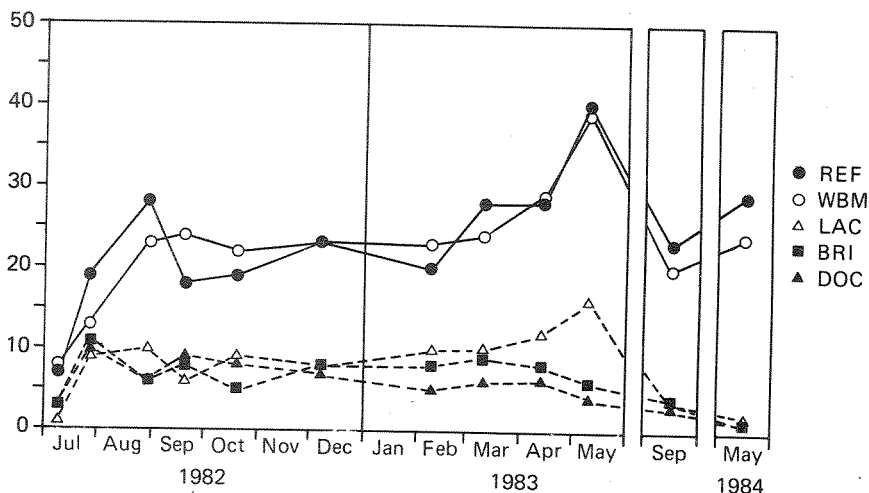

Fig. 4.3   Seasonal variation in number of taxa of macrofauna during two years colonization.
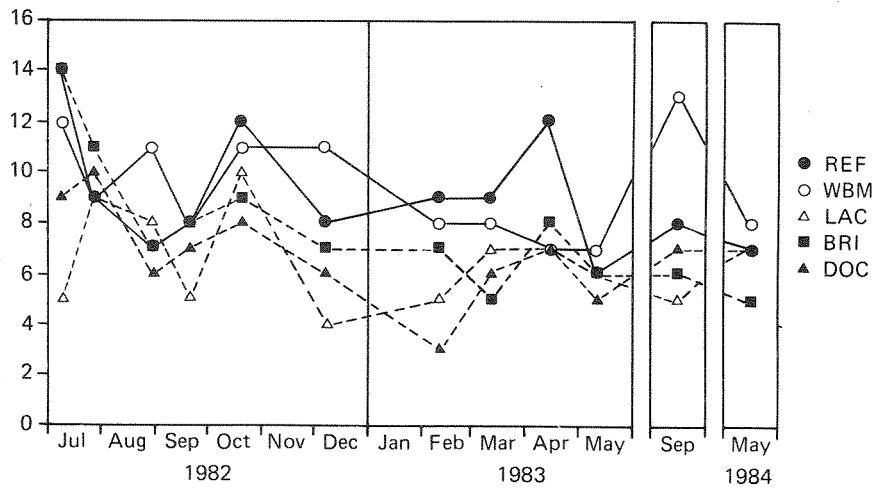
Fig. 4.4   Seasonal variation in number of taxa of meiofauna during
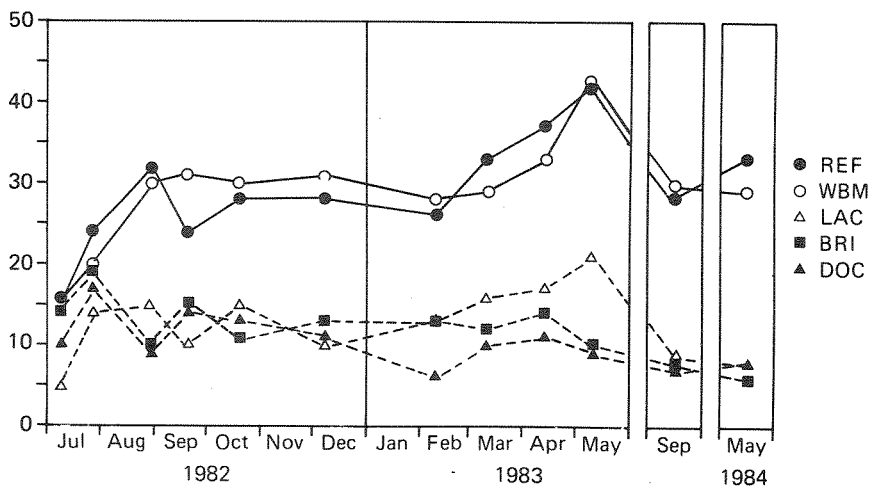   two years colonization.

Fig. 4.5   Seasonal variation in number of taxa of total fauna during
           two years colonization.

4.2.2 Individual densities

The macrofauna densities of the non-oil substrates were above 300
ind./0.01m^2 at most sampling dates except during winter 1982-83. The
WBM densities were significantly higher than those of REF, but at the
end of the 2 years the REF and WBM densities were similar (about 360
ind./0.01m^2,   Fig. 4.6). Both REF and WBM showed a clear seasonal

fluctuation. The oiled substrates had maximum density 130 ind./0.01m^2,
Fig. 4.6). From start to December 1982 these substrates varied in the
same way, but during the winter and spring 1983 the LAC densitites
exceeded those of BRI and DOC slightly . This was mainly caused by
higher densities of polychaetes in the LAC (Fig. 4.9), especially
Capitella capitata (Fig. 4.10). In September 1983 the LAC density was
below those of BRI and DOC and in May 1984 all oiled substrate
densities were extremely low (2-7 ind./0.01m^2)

In the REF and WBM substrates the densities of meiofauna individuals
were in the order of 3000-8000 ind./0.01m^2 (Fig. 4.7) with peaks in
May 1983 and May 1984. The oiled substrates had densities in the range
200 to 4500 ind./0.01m^2. A similar seasonal pattern of variation as in
the REF and WBM was observed in the LAC, BRI, and DOC except that the
densities peaked in April 1983. After that the densities decreased and
in May 1984 they were as low as 130-320 ind./0.01m^2. There was a clear
tendency that the LAC had the lowest total meiofauna densities, due to
the ciliates which occurred in BRI and DOC mainly.

As the meiofauna densities were about one order of magnitude higher
than those of the macrofauna, the total fauna densities (Fig. 4.8)
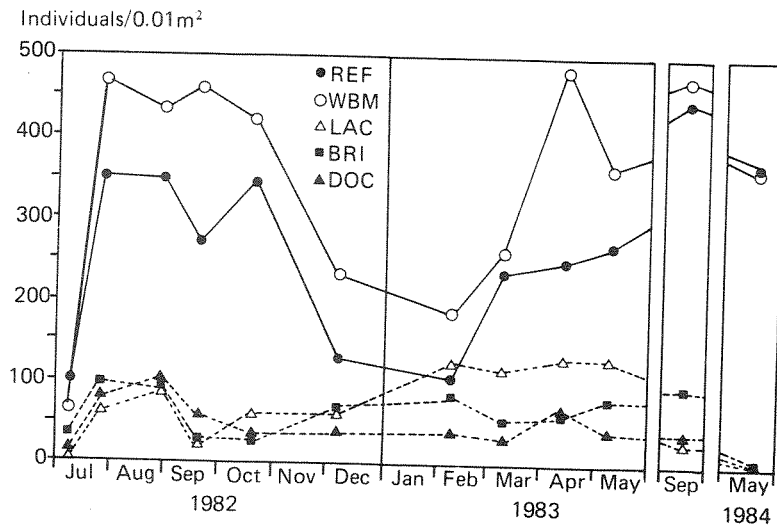reflected the former closely.

Fig. 4.6   Seasonal variation in density of macrofauna (>0.5mm) during
two years colonization. Each value is mean of four core
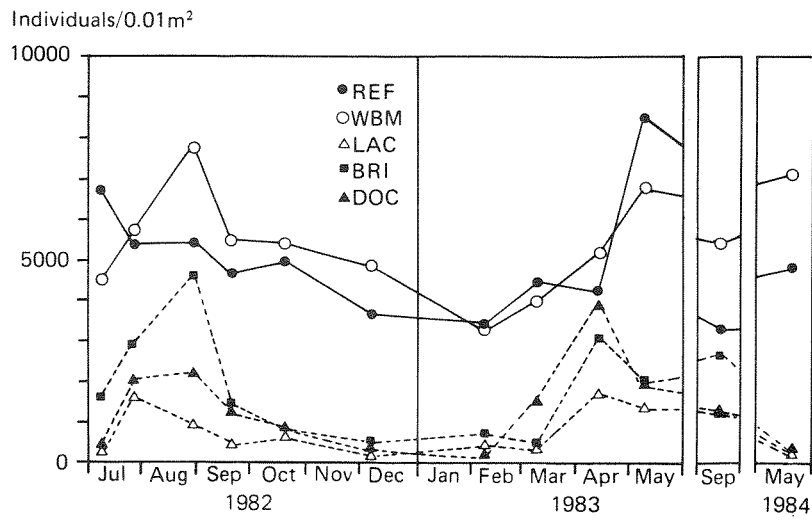sample counts.

Individuals/0.01m²

Fig. 4.7   Seasonal variation in density of meiofauna during two years
            colonization. Each value is mean of four core sample
            counts.
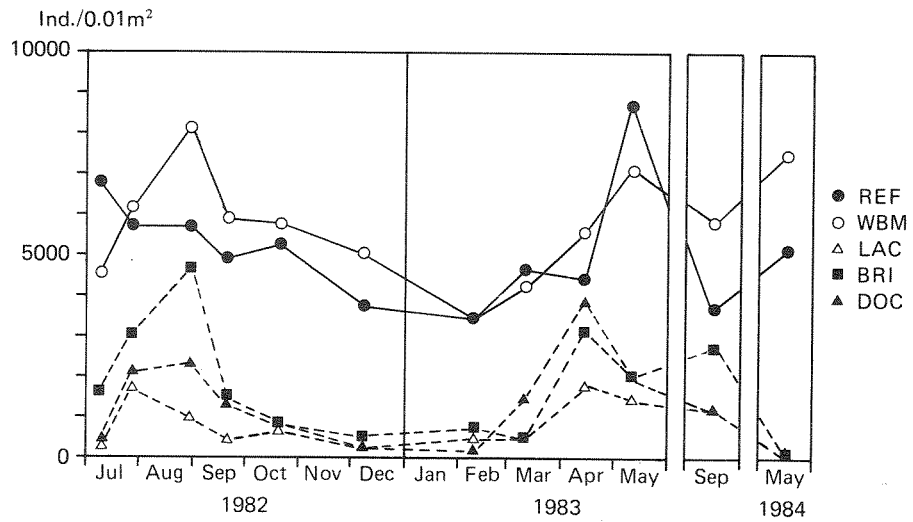
Ind./0.01m²

Fig. 4.8   Seasonal variation in density of total fauna during two
            years colonization. Each value is mean of four core sample
            counts.

4.2.3 Group densities

Polychaeta (Bristle worms)

The polychaete densities in the REF samples rose from below 10ind./0.01m^2 in July 1982 to a maximum of 350 ind./0.01m^2 in May 1983 (Fig. 4.9). After that the density declined gradually to 210 ind./0.01m^2 in May 1984. The WBM densities fluctuated around the same values as the REF. During spring 1983 the LAC densities were only slightly below these, mainly due to occurrence of Capitella capitata, but after May 1983 this population declined. In May 1984 the polychaete densities of the oiled substrates were less than 10% of the REF density.

Figures Fig. 4.10 to Fig. 4.14 show the density changes of the 6 most common polychaete species. With the exception of Protodorvillea kefersteini all species showed reduced density during the second year irrespective of substrate preference. For some, such as the two Pectinaria species, this may reflect migration of the older individuals below the upper 3 cm of the sediment. Such migration could be verified by analysis of the deeper levels of the trays. For others the decrease is assumed to reflect a real population change, which could be due to fluctuation in polychaete recruitment from one year to another, antural stabilzation and adjustment of population size, or even reflect long term limitation of the trays as simulation of benthic ecosystems. Whatever the cause was, the total polychaete densities (adults and recruits) distinguished clearly between oiled and non-oil substrates. Furthermore, no difference was found among the oiled substrates after 2 years.

The lug-worm Arenicola marina was not recorded in the core samples, but the occurrence of its characteristic faecal mounds was quite stable in all REF and WBM trays after the summer 1982 (1-5 mounds/tray). No mounds were observed in the LAC, BRI or DOC trays.
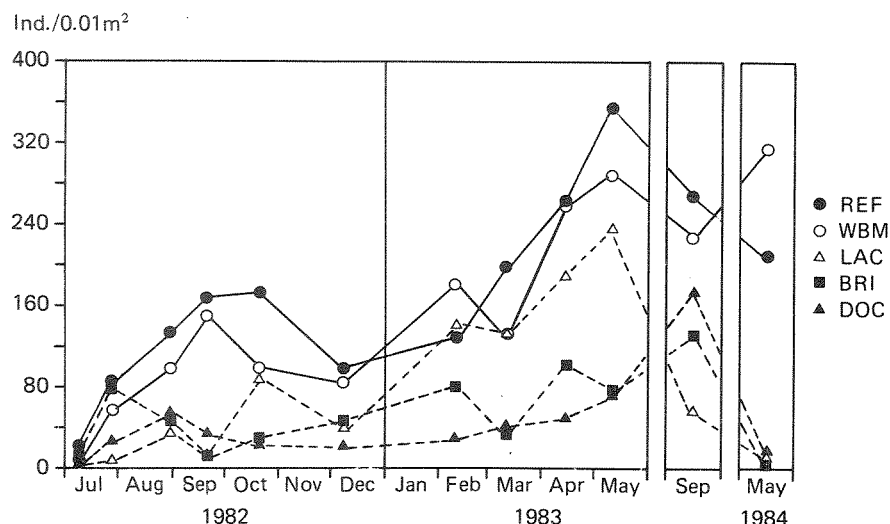

Fig. 4.9   Seasonal variation in density of polychaetes during two years colonization. Each value is mean of four core sample counts.
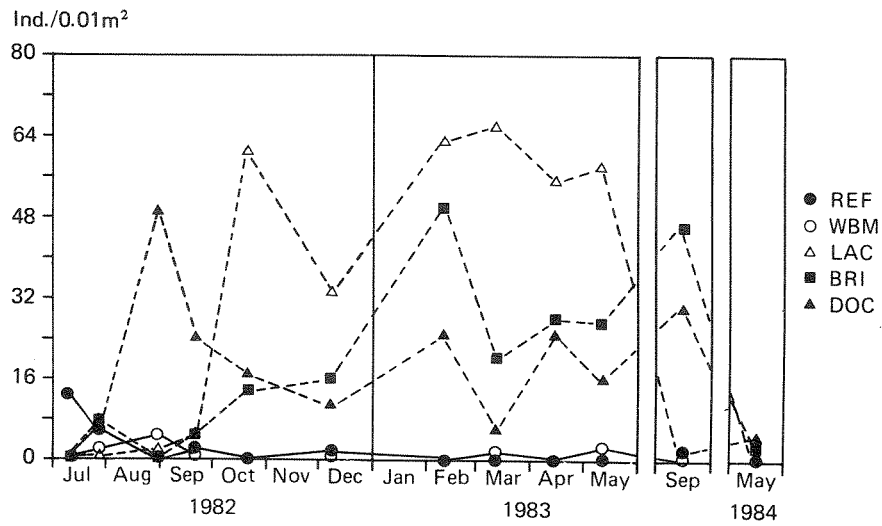
Ind./0.01m²

Fig. 4.10   Seasonal variation in density of <u>Capitella capitata</u> during
two years colonization. Each value is mean of four core
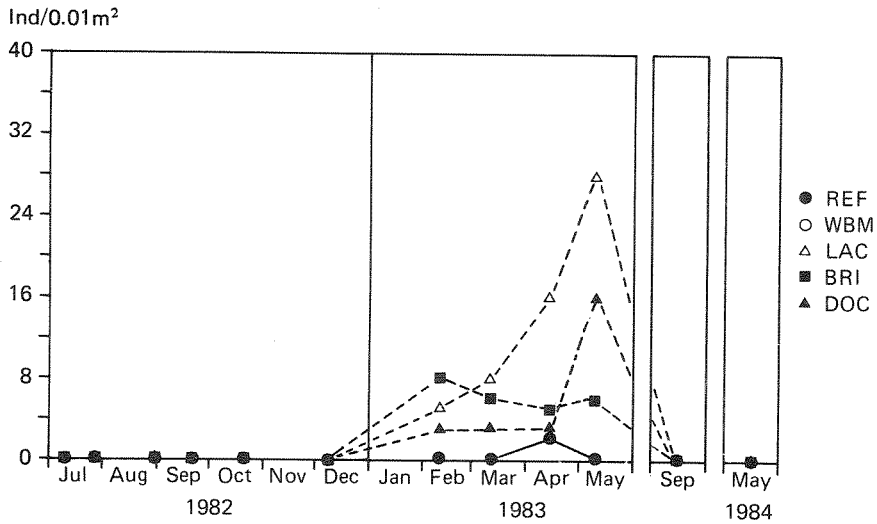sample counts.

Ind/0.01m²

Fig. 4.11   Seasonal variation in density of <u>Ophryotrocha puerilis</u>
during two years colonization. Each value is mean of four
core sample counts.

Ind./0.01m²
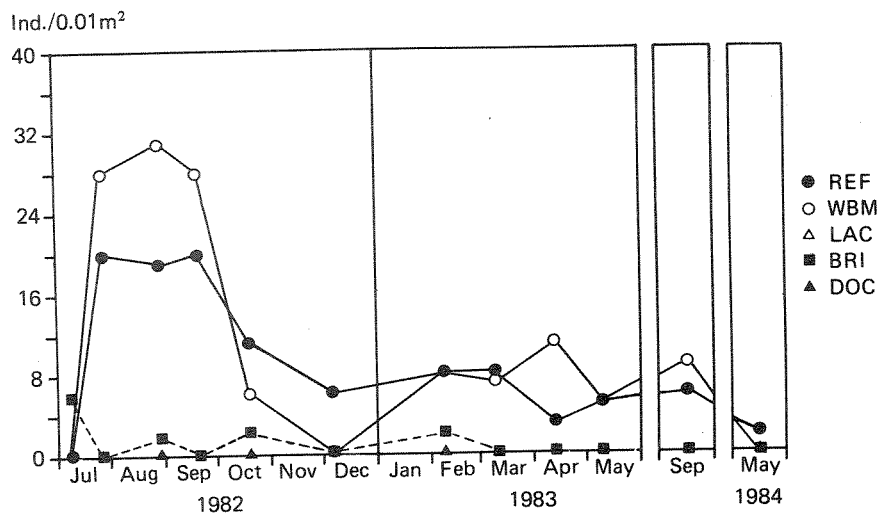

Fig. 4.12 Seasonal variation in density of the _Pectinaria_ species during two years colonization. Each value is mean of four core sample counts.
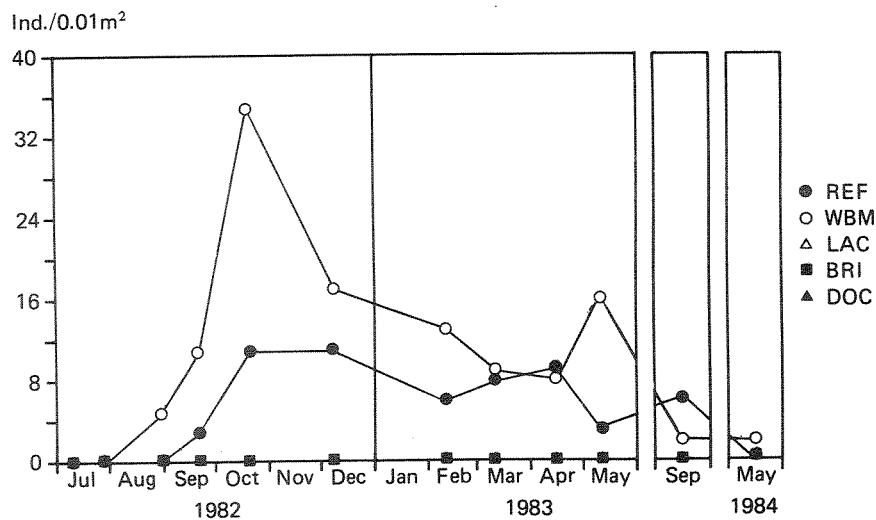
Ind./0.01m²

Fig. 4.13 Seasonal variation in density of _Prionospio malmgreni_ during two years colonization. Each value is mean of four core sample counts.
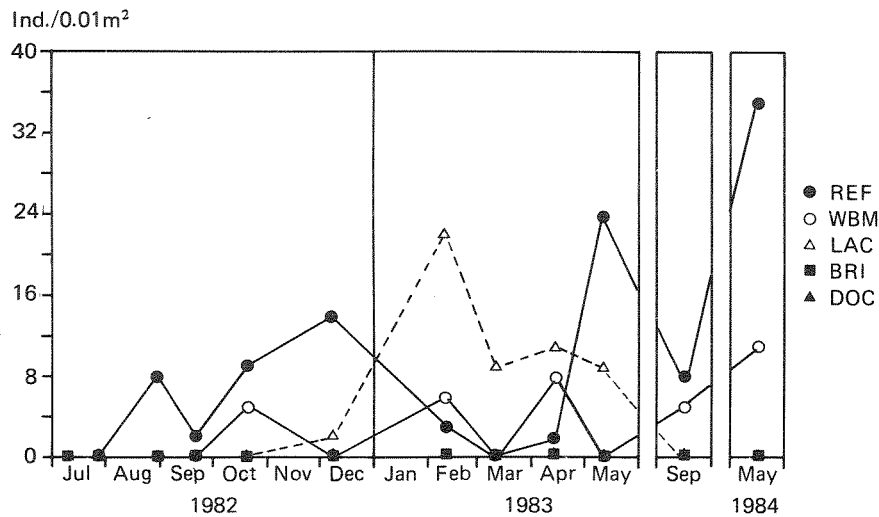
Fig. 4.14 Seasonal variation in density of <u>Protodorvillea</u> <u>kefersteinii</u> during two years colonization. Each value is mean of four core sample counts.

Bivalvia

The bivalves, which reached densities of about 50 ind./0.01m^2 in REF and WBM during the first year, also declined and nearly disappeared during the second year (Fig. 4.15). This was also reflected in the three most common species during the first year: <u>Abra nitida</u> (Fig. 4.17), <u>Tellina fabula</u> (Fig. 4.16) and <u>Parvicardium</u> sp. (Fig. 4.18). <u>Abra</u> and <u>Tellina</u> are good burrowers, and hence the decline could be due to downwards migration as with the polychaete <u>Pectinaria</u>. It is, however, unlikely that a large portion of the population would stay permanently deeper than 3 cm in the sediment, and hence the decrease is assumed to be real.

In the oiled substrates the densities declined nearly to zero within October 1982 and remained at this level for the rest of the two years, except for a small occurrence of bivalve larvae in BRI in April 1983 and in DOC in May 1984 (Fig. 4.15). Although both <u>Tellina</u> and <u>Abra</u> were found sporadically in the LAC substrate during the first year, none of them were observed there after February 1983.
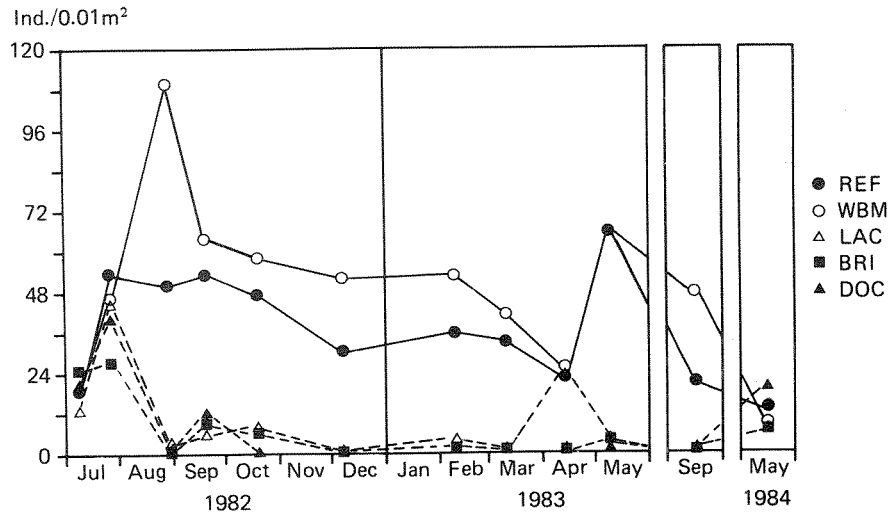
Ind./0.01m²

Fig. 4.15   Seasonal variation in density of bivalves during two   years
            colonization. Each   value   is   mean   of   four   core sample
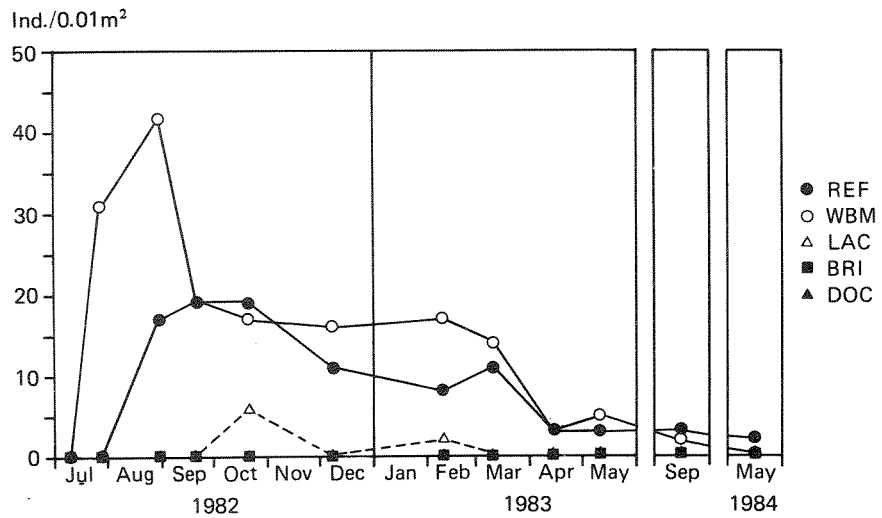   counts.

Ind./0.01m²

Fig. 4.16   Seasonal variation in density of <u>Tellina fabula</u> during two
            years   colonization. Each value is mean of four core sample
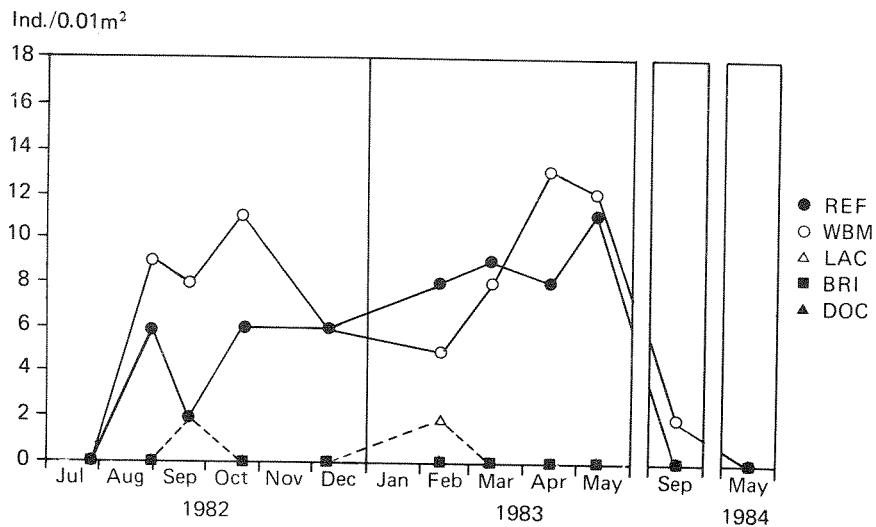   counts.

Ind./0.01m²

Fig. 4.17 Seasonal variation in density of __Abra nitida__ during two years colonization. Each value is mean of four core sample counts.
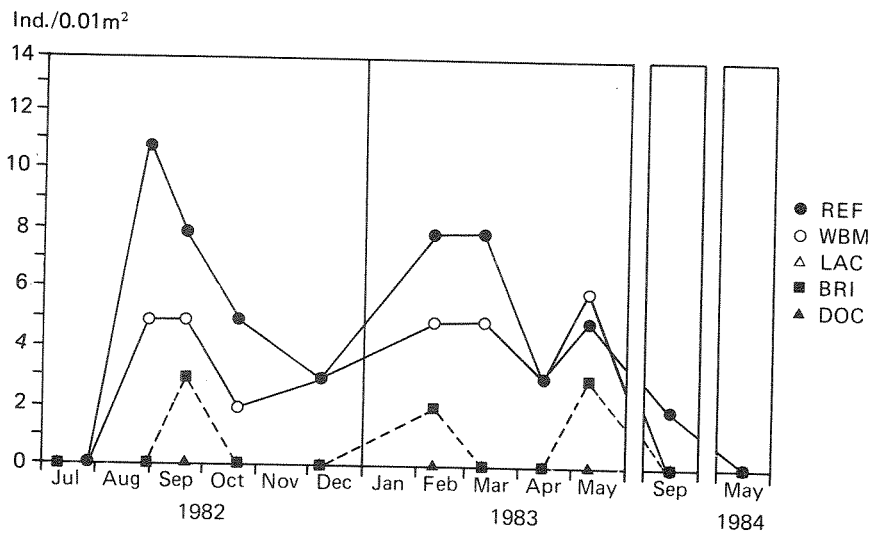
Ind./0.01m²

Fig. 4.18 Seasonal variation in density of __Parvicardium ovale__ during two years colonization. Each value is mean of four core sample counts.

Snails

__Akera bullata__, the most prominent snail species, colonized all trays rapidly, but seemed not to prefer any substrate in particular during the first year(Fig. 4.19). The population gradually declined throughout the two years. In the oiled substrates __Akera__ was not found after May 1983, whereras the non-oil trays supported a small

population also during the second year. Why the species seemed to distinguish more strongly between oiled and non-oil substrates in the second year is not known.
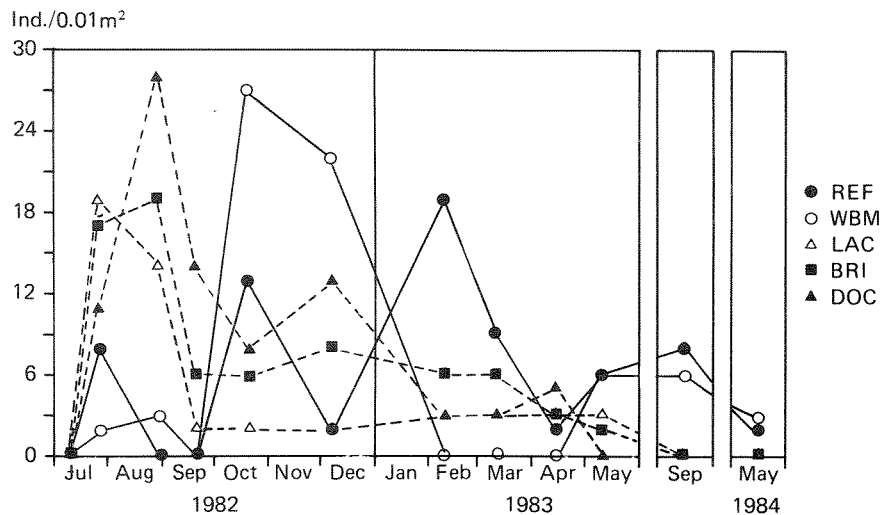

Fig. 4.19   Seasonal   variation   in density of <u>Akera bullata</u> during two years colonization. Each value is mean of four core   sample counts.

MEIOFAUNA

The meiofauna was dominated by nematods, copepods, foraminiferans, ciliates and a large component of unidentified larvae.

Nematodes

The nematodes colonized all trays gradually during July 1982, and reached peak values in August 1982, May 1983 (REF) and May 1984 (WBM) (Fig. 4.20). The populations in the oiled substrates were strongly reduced during September 1982 and did not recover for the rest of the two years.

Copepods

Both oiled and non-oil substrates showed the same seasonal fluctuation in copepod density with peaks in August 1982 and May 1983, but the REF and WBM densities were clearly above the   others   throughout   the   two years (Fig. 4.21). The populations decreased during autumn both in 1982 and 1983, but the subsequent increase during spring in   1983   was not reflected in spring 1984.

Foraminifera

The   density   of foraminiferans in REF and WBM were similar and in the range of 300-800 ind./0.01m^2. In the oiled substrate they were found sporadically   and   mainly   during the first 3 months. Contrary to the copepods, the foraminiferans showed larger fluctuations during the second year than during the first (Fig. 4.22). Whether the fluctuation

was real or reflected patchiness cannot be determined since the
meiofauna fractions of the replicate cores were pooled, but the
results showed clearly that only the non-oil substrates could support
this group of animals.

Ciliata

The clear preference of this group of animals for the diesel
substrates that was shown during the spring 1983, was also registered
in September the same year, but in the following spring very few
ciliates were recorded in any substrate (Fig. 4.23). This could have
been due to natural population fluctuation from one year to another,
but a more likely explanation is that the ciliate density was
regulated by the amounts of detritus on top of the oiled trays. Due to
settling and resuspension of debris this layer was not generally as
stable as indicated during autumn and winter 1982/83.
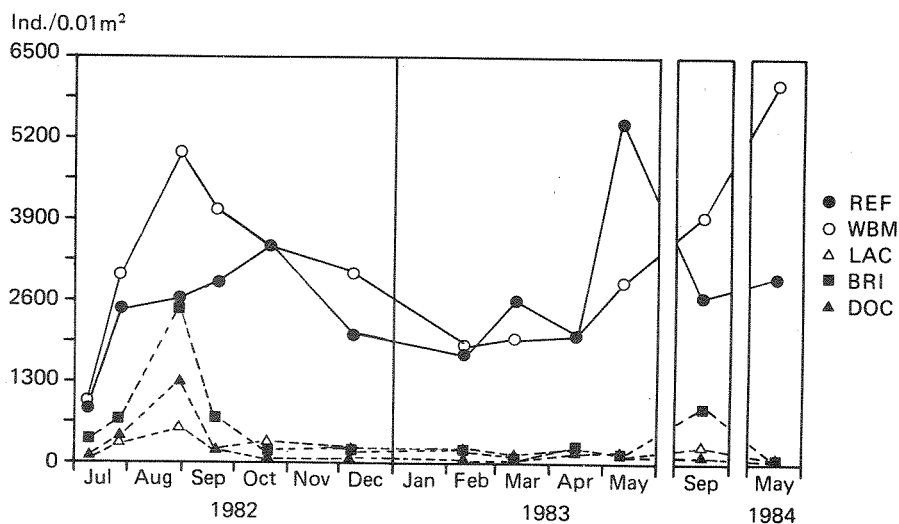

Fig. 4.20 Seasonal variation in density of nematodes during two years
colonization. Each value is mean of four core sample
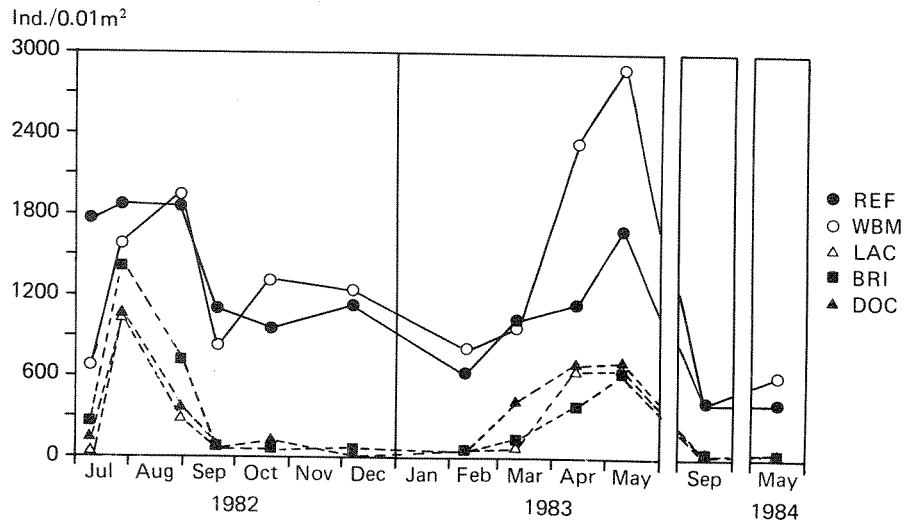counts.

Fig. 4.21   Seasonal variation in density of copepods during two years colonization. Each value is mean of four core sample counts.
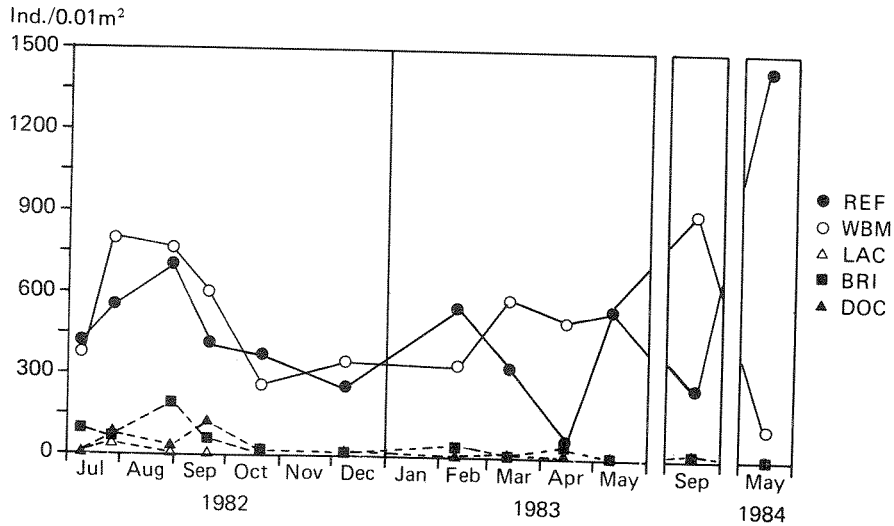

Fig. 4.22   Seasonal variation in density of Foraminifera during two years colonization. Each value is mean of four core sample counts.
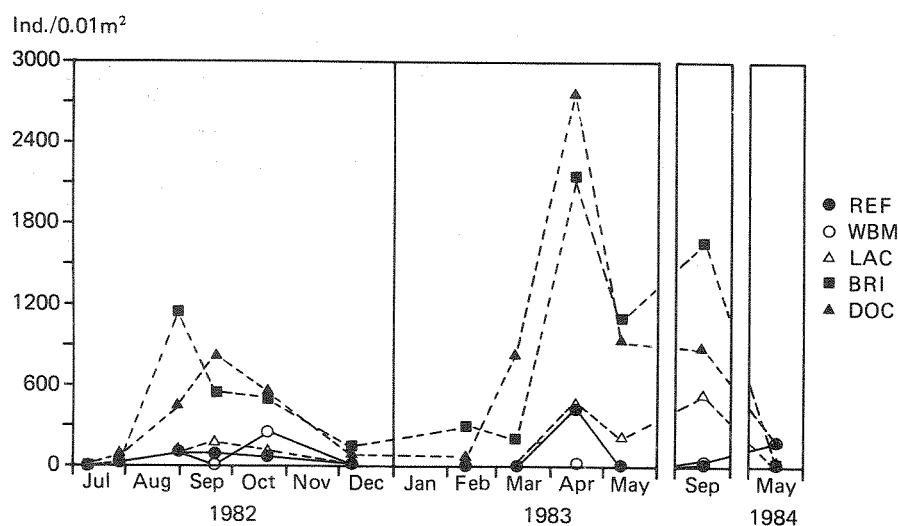
Ind./0.01m²

Fig. 4.23 Seasonal variation in density of Ciliata during two years colonization. Each value is mean of four core sample counts.

4.2.4 Community parameters

The community indices were calculated on basis of both total fauna and of macrofauna alone. The latter gave the clearest and most meaningful results, and only when leaving out the larger individuals of typical meiofauna such as nematodes and copepods. The reason for this is that most macrofauna were identified to species or at least to genus, whereas the meiofauna were classified to higher levels giving groups with large number of individuals, and hence, strong influence on the index values. Due to this, only the macrofauna indices are discussed below.

Shannon-Wiener diversity

The REF and WBM diversities were almost identical after August 1982 and increased slightly from about 2.5 to 3.4 in the course of winter and spring 1983 (Fig. 4.24). The value 3.4 is fairly high and shows that these communities approached a complexity comprable to mature sediment communities within one year. This was followed by a decrease to 1.9 in September 1983 which was somewhat lower than in September the year before (2.6). In May 1984 the diversity was 2.7 and 2.4 respectively for REF and WBM which was less than one year before, and which reflected the decrease in polychaetes and bivalves during the second year of colonization.

The oiled substrates did also show a rapid increase in diversity in July 1982 from 0 to 2.0, but this was followed by a gradual decline in BRI and DOC almost to zero in May 1984. The LAC diversity rose slightly in spring 1983, but only temporary. In May 1984 the LAC diversity was as low as that of BRI and DOC.

The evenness component of diversity (cf. Bakke & al. 1985a, Fig 4.59) showed highest value in the REF and WBM substrates during the first year, and this trend continued until September 1983 although the evennes of all substrates went down after the summer 1983. In May 1984 the REF and WBM evenness had rose nearly to the level one year before. The evenness values of the oiled substrates for May 1984 were meaningless due to the low densities and occurrence of Capitella as the only real macrofauna.
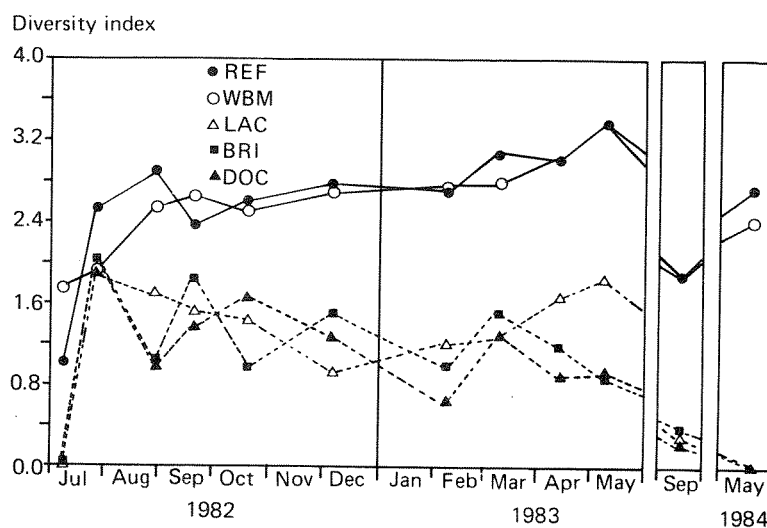

Fig. 4.24   Seasonal variation in diversity (H) for macrofauna during two years colonization. Nematodes and copepods have been omitted. Each value is based on the mean individual density values from one substrate.

Dominance index

The REF and WBM index values were in the range of 10-20% throughout most of the first year and gradually decreased as more taxa appeared in spring 1983 (Fig. 4.25). In September 1983 dominance had increased slightly (40-42%), but decreased again to 24-32% in May 1984. The dominance in the oiled substrates increased gradually to 100% (Capitella only) in May 1984.
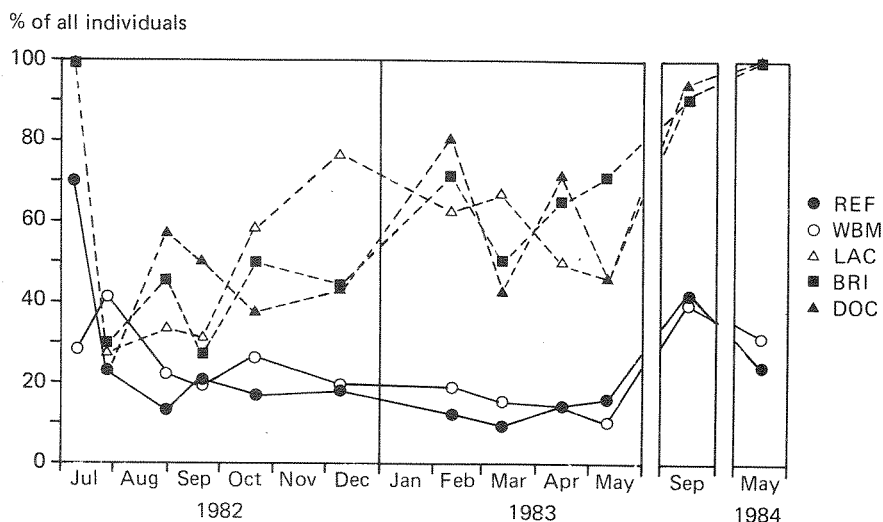
% of all individuals

Fig. 4.25 Seasonal variation in dominance index of macrofauna during
two years colonization. Nematodes and copepods have been
omitted. Each value is based on the mean individual density
values from one substrate.

Dominance profiles

These were constructed on basis of the macrofauna without the
nematodes and copepods. The trends were clear (Fig. 4.26). The REF and
WBM profiles showed a dominant situation at the beginning experiment,
whereafter the profiles became gradually more horizontal as an
increasing number of taxa colonized the trays. A slight increase in
dominance was indicated in September 1983, but in the following spring
the profile was back to the condition one year before.

The profiles of the oiled substrates were quite different from this
pattern, but they were similar to one another (Fig. 4.26). None of
them had any real macrofauna in the beginning of July 1982. From
August 1982 all three had more dominant communities than the REF and
WBM, and this dominance increased gradually to 100% in May 1984. As
expected from the temporary somewhat larger number of taxa in LAC
during spring 1983 the LAC dominance was less than that of BRI and DOC
in April and May 1983, but after that there was no difference between
the oiled substrates.

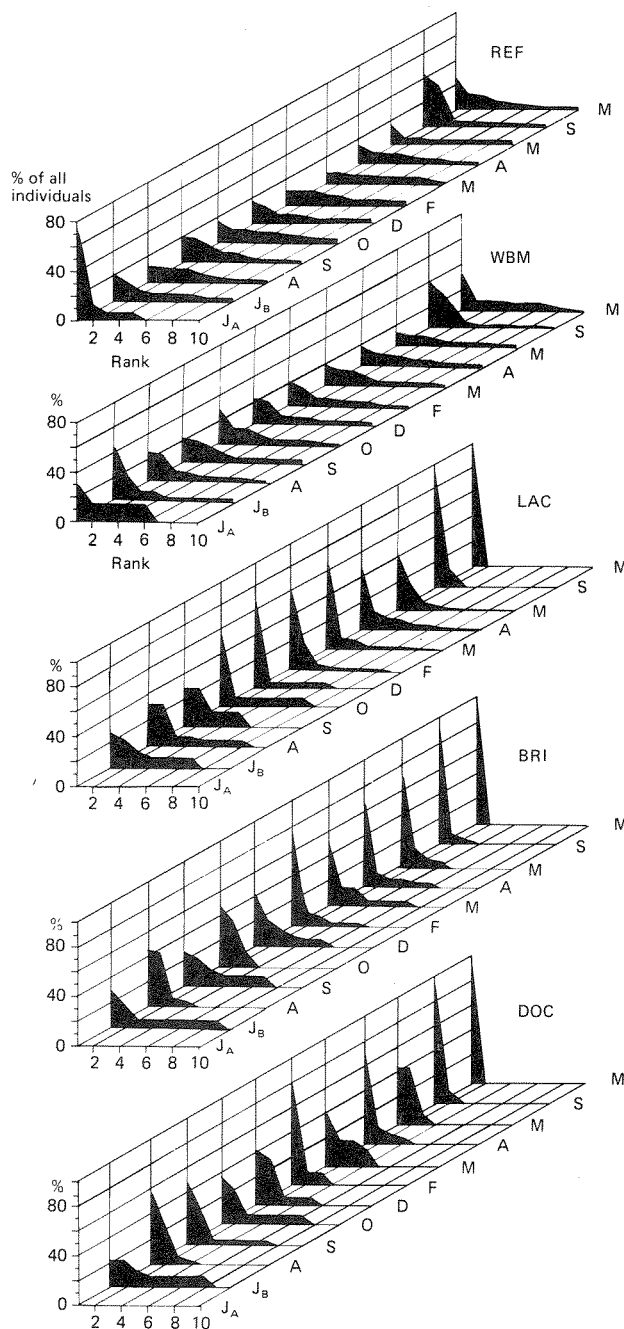Fig. 4.26 Dominance profiles of the macrofauna based on the 10 most
           abundant taxa (leaving out nematods and copepods) ranked by
           decreasing abundance along the abscissa and scaled by
           dominance value (percent of total number of individuals)
           against the ordinate. The third axis indicates the changes
           in profiles with time (month initials given).

NIVA:0-82003,Rekolj

4.2.5 Discussion of fauna colonization

The main conclusion after the first year of this experiment was that fauna charateristics separated the substrates into two groups: the non-oiled and the oiled. Within these groups the differences in densities and in composition and succession of species were small, though in many cases clear. The non-oiled substrates reflected a normal succession at clean substrates in contrast to the "pollution type" succession at the oiled substrates. This difference in development of the communities was mainly an indirect effect of the oil through its influence on sediment conditions, the lid effect.

The secon year comprised only 2 sampling surveys compared to 10 during the first year, but the general impression was that these trends continued.

The REF and WBM development were closely related, and both substrates showed slight signs of reduced community richness compared to the first year. There are several possible explanations for this. A reduction in burrowing species such as bivalves and some polychaetes, could be due to migration from the sediment surface to deeper levels as the individuals grew in size. They could then stay below the 0-1 cm sediment section analysed for September 1983, and possibly also below the 0-3 cm section analysed in May 1984. It is however unlikely that these individuals, which were less than 2 years old in May 1984, would stay a significant part of their time at such depth in the sediment. The community reduction in REF and WBM is therefore considered to be real, and was not unexpected. The unusually high diversity index and high evenness in spring 1983 compared to other recolonization experiments (e.g., Arntz & Rumohr 1982) indicated an "overshoot" in community development, and that the conditions in the second year was result of further stabilization. It is quite normal that intense colonization is followed by reduced densities the year after as the populations are stabilized through competition and predation. The present design with initial non-animal substrates would also offer a multitude of vacant ecological niches to potential settlers, and this may have increased an initial overshoot in colonization intensity even more.

Yet one cannot rule out the possibility that the experimental design itself (tray size, current pattern, sediment depth etc.) could have some sort of negative influence on colonization which did not manifest itself until after the first year, although the sediment chemistry did not indicate any adverse development.

The community development in the oiled substrates was poor. Animal colonization could only occur in the layer of detritus on top of the cuttings and during the second year the communities collapsed completely.

The community collapse could be due to several factors. The chemical analysis showed signs of biodegradation of the oil after 15 months, presumably in the transition zone between cuttings and detritus where oxygen may have been present. Degradation products of oil are generally more toxic than the original hydrocarbon and this process could therefore have caused a build up of toxic components in the detritus. A second factor was the fact that the detritus layer itself was not generally as stable in thickness as indicated during the winter 1983, due to resuspension of matter. Such loss of the detritus would cause loss of the accompanying fauna. A third factor is that the initial colonization of the oiled substrates could have been an overshoot as in the non-oil substrates, and that the detritus was not able to support any permanent fauna.

Hence, in spite of the slight temporary improvement of the low aromatic cuttings over diesel cuttings during the first year, no real sign of biological recovery from the discharged oil based cuttings could be found within two years, irrespective of the kind of base oil used in producing the cuttings.

5 References

Arntz, W.E., and Rumohr H., 1982. An experimental study of macrobenthic colonization and succession, and the importance of sesonal variation in temperate latitudes. J.Exp.Mar.Biol.Ecol, 64:17-45.

Bakke, T., 1981. Project to investigate the recolonization of benthic organisms on sedimentary bottoms covered by discharged drill cuttings, and the possible leakage of contaminants from the cuttings to the water. Norwegian Institute for Water Research. Research proposal O-82003, 15pp.

Bakke,T., Green, N.W., Næs, K., Pedersen, A., Sporstøl, S., and Oreld, F., 1985a. Drill cuttings on the sea bed. Field experiment on recolonization and chemical changes. Phase 1. Thick (10 mm) layers of cuttings 1982-1983. NIVA Report O-82003. Oslo. 202pp.

Bakke,T., Green, N.W., Næs, K., Pedersen, A., Sporstøl, S., and Oreld, F., 1985b. Drill cuttings on the sea bed. Field experiment on recolonization and chemical changes. Phase 2. Various thicknesses (0.5, 1, 3, 5, and 10 mm) of cuttings 1983-1984. NIVA Report O-83102. Oslo. 152pp.

Elmgren, R., 1973. Methods of sampling sublittoral soft bottom meiofauna. Oikos, 15:112-120.

Grahl-Nielsen, O., Sundby, S., Westerheim, K. and Wilhelmsen, S., 1981. Petroleum hydrocarbons in sediment resulting from drilling discharges from a production platform in the North Sea. In: Proceedings from Symposium on Research on Environmental Fate and Effects of Drillings Fluids and Cuttings. Florida. Vol. 1.

Pielou, E.C., 1975. Ecological Diversity. New York, Wiley.

Shannon, C.E and Weaver, W., 1963.The Mathematical Theory of Communication, Univ.of Illinios Press, Urbana. 118pp..

Shaw, K.M., Lambshead, P.J.D. and Platt, H.M., 1983. Detection of pollution-induced disturbance in marine Benthic assemblages with special reference to nematodes. Mar.Ecol.Prog.Ser., 11:195-202.